SYNOPSIS

Aluminium alloys, which are the most widely used materials in the aircraft and aerospace industries, find their applications due to high strength–to-density ratio, resistance to catastrophic fracture, high degree of toughness, fabricability including good weldability and availability. High strength aluminum alloys are used in different forms like sheets, forgings and extruded rods, welded and machined components in the aerospace industry. One major application of the aluminium alloys in the space sector is in the launch vehicle and satellite sub-systems. The Indian Space Research Organization has met major challenges of indigenization of suitable aluminium alloys, for example, Al-Cu alloys (like AA2219) and Al–Zn-Mg alloys (like AA7075 and AFNOR 7020).

Many failures of the metallic sub-systems made of different grades of aluminum alloys have confirmed that high levels of residual stresses and unacceptable microstructures have played a role. Crystallographic texture in these materials has a very significant role to play in the performance of these materials in service. The anisotropy in the mechanical properties caused by crystallographic texture would add to the woes of the existing problems of residual stresses and directionality in the microstructure. In this context, a detailed study of crystallographic texture and residual stresses of high strength aluminium alloys is mandatory. It is also important to study the influence of texture on the anisotropy in mechanical properties. The present research programme aims at addressing some of these aspects.

The entire work has been divided in three major sections, namely macro and micro texture analysis, non-destructive measurement of residual stresses using X-ray Diffraction (XRD) and the Ultrasonic Testing (UST) and the study of anisotropy in the mechanical properties arising due to the above two factors. The thesis composition is as follows.

In Chapter I, a detailed survey of the literature has been presented wherein basic physical metallurgy for different aluminum alloys of interest has been given. Thereafter, details of texture measurement by the X-ray diffraction and Electron Back Scatter Diffraction (EBSD) are presented. This is followed by a detailed review on the texture studies carried out in aluminium alloys under various conditions. Literature review on the two non-destructive methods, namely the X-ray diffraction and ultrasonic method has been carried out in detail. In order to account for microstructural changes, Differential Scanning Calorimetry (DSC) was carried out. Recent work on the mechanical property anisotropy arising due to high degree of mechanical working in aluminium alloys has been reviewed.

Chapter II includes the experimental details involved in the course of the present investigation. The procedural details of cold rolling and associated microstructural changes are given in this chapter. This is followed by the texture measurement methods. Experimental details of the bulk texture measurement using the X-ray diffraction and micro texture measurements by the Electron Back Scatter Diffraction (EBSD) in the SEM are described. Details of the texture computation procedure as well as micro texture analysis methods are also presented. Basic principles of the non-destructive methods of measuring residual stresses, viz., the X-ray diffraction and the Ultrasonic testing, including the theory of measurements, are dealt with. Finally, the details of measurements of anisotropy in mechanical properties, including simulation carried out, for the three alloys are delineated.

Chapter III deals with the results of the crystallographic texture measurements carried out on the cold rolled and artificially aged aluminium alloys. Results obtained from the pole figure analysis, Orientation Distribution Function (ODF) method and estimation of the various fibres present in the cold rolled material and the volume fraction of the texture components are discussed in detail for the three aluminium alloys. Results of the micro texture measurements using the EBSD are presented, explained and analyzed in detail. A comparison of the inverse pole figures (IPFs), Image Quality (IQ) maps, Misorientation angle, Grain Orientation Spread (GOS), Kernal Average Misorientation (KAM), CSL boundaries, Grain size and Grain boundary character distribution (GBCD) for materials cold rolled to different reduction for each of the alloys are done and analyzed. Conclusions are drawn regarding the evolution of texture from the above analysis. Deformation texture components Cu, Bs and S increase from the starting material as the rolling percentage increases. On the other hand, recrystallization texture components of Goss and Cube are observed to be weak. AFNOR 7020 developed the strongest texture followed by the AA7075 and AA2219 alloys. The Bs component is stronger in AFNOR 7020 alloy. This is attributed to the shear banding. Average KAM value increases as the cold working in the material increases confirming that the material contains high dislocation density at higher working percentages.

Chapter IV deals with residual stresses in the aluminium alloys. Measurement of residual stresses has been carried out on the same sheets and plates, wherever it was possible, using the two methods. The residual stresses have been measured in two mutually perpendicular directions of the aluminium alloy sheets. Residual stress measurements by the ultrasonic method using the Critically Refracted Longitudinal ($L_{CR)}$ wave technique is also used to measure the subsurface stresses non-destructively. Acousto Elastic Coefficients (AEC) is determined for the alloys, in uniaxial tension. Using the AEC for the alloys, the RS at a depth of 3mm are evaluated using a 2MHz probe. Results of the stresses measured by the two methods have been discussed. The trends and anisotropy in the stress values due to texture are discussed and compared with the literature available. Surface residual stresses by the XRD method show compressive stresses at a majority of the locations. Residual stresses measured by the ultrasonic technique, which has a depth of penetration of about 3mm, have shown tensile stresses on many locations. Residual stresses are influenced by the crystallographic texture. Anisotropy in stress values in the longitudinal and transverse directions is demonstrated.

In Chapter V, the anisotropy in mechanical properties for the three alloys is discussed in detail. The anisotropy in the three directions, namely the parallel, transverse and 45 deg orientation to the rolling directions is evaluated. The Lankford parameter, otherwise known as Plastic Anisotropy Ratio “r”, has been measured from the tensile tests of the alloy samples in the cold rolled conditions. These have been compared with the computed “r” from the XRD ODF data using the VPSC simulations and found to be qualitatively matching. These trends are discussed with the available literature on the anisotropy of the mechanical properties for aluminium alloys. Samples subjected to high cold rolling show anisotropy of UTS, YS and ‘n’ values. Experimentally measured “r” values in all the deformation conditions match the trend qualitatively with the simulated ones. The maximum anisotropy was observed at 45^{o} orientation to the rolling direction in all the three alloys.

Chapter VI gives the summary of the results from the study and the suggestions for future work.